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During the period under review, the main effort of the research supported by this grant was concentrated onTitan, Iapetus, and two comets, Comet Hyakutake and Comet Hale-Bopp. Significant discoveries were made in each case as summarized in the report.

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University of Hawai'i at Mānoa

Institute for Astronomy
2680 Woodlawn Drive • Honolulu, Hawai'i 96822

June 19, 1998

Ms. Theresa A. Curtis
Code 216.0
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

SUBJECT: Grant No. NAG5-5030

Dear Ms. Curtis:

Please find enclosed the Annual Progress Report for the subject grant entitled, "Spectroscopic Observations of the Planets." Copies are also being provided to Dr. Jay T. Bergstralh, NASA Technical Officer, the Center for Aerospace Information (CASI) and the Defense Technical Information Center (DTIC).

We request that the second year funding increment of $53,000 be formally obligated and released to the University of Hawaii. Please find enclosed a revised budget for the second year of this project. Please ensure that all correspondence to this request is directed to Mr. Marvin S. Enokawa, Director of Research Services, Office of Research Services, 2530 Dole Street, Sakamaki D-200, Honolulu, Hawaii 96822.

Thank you for your consideration of this request.

Sincerely yours,

Tobias C. Owen
Principal Investigator
Institute for Astronomy

ENDORSED BY:

Robert A. McLaren
Interim Director
Institute for Astronomy

Marvin S. Enokawa
Director of Research Services
Office of Research Services

enclosure

University of Hawaii

Annual Performance Report

Submitted to the

National Aeronautics and Space Administration

Grant No. NAG5-5030

"Spectroscopic Observations of the Planets"

July 1, 1997 to June 30, 1998

Submitted by

Tobias Owen
Principal Investigator
Institute for Astronomy
University of Hawaii

SPECTROSCOPIC OBSERVATIONS OF THE PLANETS

During the period under review, the main effort of the research supported by this grant was concentrated on Titan, Iapetus, and two comets. Significant discoveries were made in each case, as summarized below:

1. TITAN

Using the United Kingdom Infrared Telescope (UKIRT) and a cooled grating spectrometer (CGS4), we discovered a new window into Titan's atmosphere at 2.7 μm and found evidence for thick, transient clouds in the satellite's lower atmosphere. (This is a collaboration with C. Griffith and T. Geballe). Most of this new window is curtained off from the Earth's surface by strong absorptions from CO_2 and H_2O. However, with the excellent observing conditions at Mauna Kea, it is possible to see through the long wavelength edge of the window at 2.85 — 2.95 μm.

The surface of Titan is extremely dark at this wavelength, with an albedo of about 3%. However, we found a much higher flux from this window during one night's observation, and on that same night, the fluxes from previously established windows at shorter wavelengths were also much higher than usual. We have interpreted this result as an indication of cloud activity in Titan's lower atmosphere.

Under normal conditions, the albedos determined in Titan's windows can be used to constrain the composition of the satellite's surface. We have reobserved the 5 μm window with this in mind as well, and interpreted the results using models for the surface developed by Ted Roush at NASA Ames. The best fit achieved so far requires the presence of water ice with some darkening agent such as amorphous carbon. There is no clear signature of organic material such as tholins on Titan's leading hemisphere. This may reflect the dominance of the continent-sized bright feature on that hemisphere. We do not yet have a suitable spectrum of the trailing hemisphere.

These results have been presented at the April 1998 meeting of the European Geophysical Society and the May 1998 Galileo-Cassini meeting in Nantes. An article describing this work has been submitted to *Nature* for publication.

2. IAPETUS

Again with UKIRT and CGS4, we have succeeded in recording the spectrum of the darkside of Iapetus from 2.85 - 3.85 μm. (This is a collaboration with D. Cruikshank, T. Geballe, T. Roush, and C. Delle Ore.) We have confirmed the existence of a very strong absorption at 2.9 μm, which appears to result from organic material that is rich in nitrogen. The so-called "Triton-Tholin" studied by Bishun Khare and collaborators appears to match the feature rather well, when mixed with amorphous carbon and water ice. However, there is a feature at the longward end of the spectrum that is not matched by this mixture. We are planning to extend our coverage of the darkside spectrum to 4.25 μm with new observations this year in order to define this new feature.

3. COMETS HYAKUTAKE AND HALE-BOPP

Each of these comets was observed with the James Clerk Maxwell Telescope to study isotope ratios for comparison with the Earth. In both cases, it was possible to determine a value of D/H in H_2O, which was $2.9 \pm 1.0 \times 10^{-4}$ in Hyakutake and $3.2 \pm 1.2 \times 10^{-4}$ in Hale-Bopp. These numbers are in good agreement with the original determination of $3.16 \pm 0.34 \times 10^{-4}$ Halley's comet by in situ measurements with mass spectrometers on the Giotto Spacecraft. Thus we think all comets probably exhibit this same value, of D/H in H_2O, which is about twice the value of 1.56×10^{-4} in seawater on Earth. We conclude that melting comets will not produce the Earth's oceans — mixture of cometary water with some low D/H reservoir is required.

In the case of Hale-Bopp, we were also able to measure D/H in HCN, and found it to be 7 times higher than the value in H_2O. This is exactly the kind of difference in D/H found in interstellar clouds that have "warm"

regions with temperatures near 50 K. We conclude from this that comets indeed preserve interstellar materials that have undergone little modification.

This work was carried out with several different collaborators, as indicated by the publication list below.

PUBLICATIONS 1997-1998

"Mars: Was there an Ancient Eden?" T. Owen. In *Astronomical and Biochemical Origins and the Search for Life in the Universe*, ed. C. B. Cosmovici, S. Bowyer and D. Werthimer (Editrice Compositori: Bologna) 203 (1997).

"The Detection of Water Ice in Comet Hale-Bopp" by J. K. Davies, T. L. Roush, D. P. Cruikshank, M. J. Bartholomew, T. R. Geballe, T. Owen, C. de Bergh. *Icarus* **127**, 238 (1997).

"Millimeter and Submillimeter Hetrodyne Observations of Titan: Is Carbon Monoxide Really Well-Mixed in its Atmosphere?" T. Hidayat, A. Marten, B. Bèzard, D. Gautier, T. Owen, P. F. Matthews, G. Paubert. *Icarus* (in press) (1997).

"The Surfaces of Pluto and Charon" D. P. Cruikshank, T. L. Roush, J. M. Moore, M. V. Sykes, T. Owen, M. J. Bartholomew, R. H. Brown, K. A. Tryka. In *Pluto and Charon*, ed. D. J. Tholen and S. A. Stern (Tucson, Univ. of Arizona Press) p. 221-268 (1997).

"From Planetesimals to Planets: Contributions of Icy Planetesimals to Planetary Atmospheres" T. Owen. In *Stardust to Planetesimals*, ed. Y. J. Pendleton and A. G. G. M. Tielens (Astron. Soc. Pac. Conf. Series) **122**, 435-450 (1997).

"First Ground-Based Adaptive Optics Observations of Neptune and Proteus" F. Roddier, C. Roddier, A. Branic, C. Dumas, J. E. Graves, M. J. Northcott, and T. Owen. *Planet. Space Sci.* **45**, 1031-1036 (1997).

"High-resolution Ten-micron Spectroscopy of Ammonia and Phosphine Lines on Jupiter" L. M. Lara, B. Bèzard, C. A. Griffith, J. H. Lacy, and T. Owen. *Icarus* (in press) (1998).

"Measurements of $^{12}C/^{13}C$, $^{14}N/^{15}N$ and $^{32}S/^{34}S$ Isotope Ratios in Comet Hale-Bopp (C/1995 O1)" D. C. Jewitt, H. E. Matthews, T. Owen, and R. Meier. *Science* **278**, 90-93 (1998).

"A Determination of the HDO/H_2O Ratio in the Comet C/1995 O1 (Hale-Bopp." R. Meier, T. Owen, H. E. Matthews, D. C. Jewitt, D. Bockélee-Morvan, N. Biver, J. Crovisier, D. Gautier. Science 279, 842-844 (1998).

"Deuterium in Comet C/1995 O1 (Hale-Bopp): Detection of DCN" R. Meier, T. C. Owen, D. C. Jewitt, H. E. Matthews, M. Senay, N. Biver, D. Bockélee-Morvan, J. Crovisier and D. Gautier. *Science* **279**, 1707-1710 (1998).

"Deuterated Water in Comet C/1996 B2 (Hyakutake) and its Implications for the Origin of Comets" D. Bockélee-Morvan, D. Gautier, D. C. Lis, K. Young, J. Keene, T. Phillips, T. Owen, J. Crovisier, P. F. Goldsmith, E. A. Bergin, A. Despois and A. Wootten. *Icarus* (in press) (1998).

"Storms on Titan" C. A. Griffith, T. Owen, G. A. Miller, and T. Geballe. *Nature* (submitted) 1998.

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